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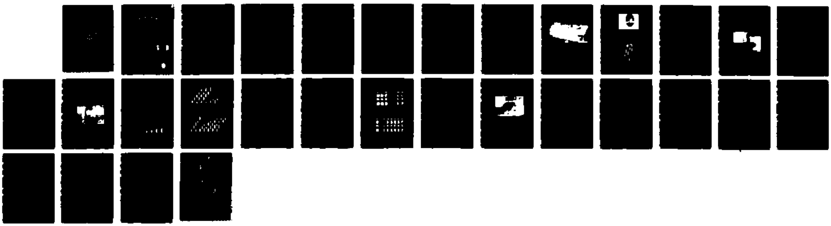

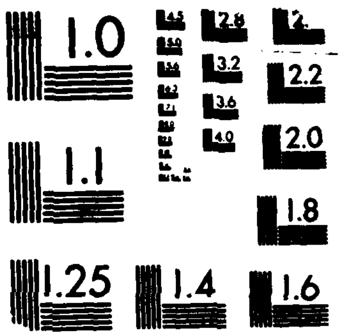

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BEHAVIORAL RESPONSE OF RATS EXPOSED TO HIGH-POWER MICROWAVE RADIATION

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Interim Report for Period September 1986 - January 1987

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USAF SCHOOL OF AEROSPACE MEDICINE
Human Systems Division (AFSC)
Brooks Air Force Base, TX 78235-5301

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NOTICES

This interim report was submitted by personnel of the Radiation Physics Branch, Radiation Sciences Division, USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas, under job order 7757-01-1N.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility nor any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, nor otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources-National Research Council.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
Emerging high-power microwave technologies require that bioeffects of exposure to this type of radiation be investigated for health and safety considerations. Disruption of animal behavior is reported to be a sensitive indicator of microwave exposure. Three behavioral tasks were chosen for this initial investigation of exposure to U.S. Air Force high-power microwave emitters. The tasks were: (1) single trial avoidance, (2) water satiation, and (3) rotarod performance. The emitters used were the USAFSAM peak power simulator and the Gypsy virtual cathode oscillator emitter at the Air Force Weapons Laboratory, Kirtland AFB, New Mexico. Exposure to high-power microwave radiation from the USAFSAM peak power simulator significantly affected the single trial avoidance task. Neither the single trial avoidance

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19. ABSTRACT (Continued)

task nor rotarod performance was affected by the Gypsy emitter. However, animals exposed to 9 kW and 11 kW outputs from the USAFSAM emitter spent significantly less time imbibing water postexposure than sham-exposed animals. The most consistent finding in the animals exposed to the Gypsy pulses was that those exposed at 4 m (13.1 ft) spent significantly less time drinking water than those exposed at 1 m (3.28 ft). This paradoxical result may be due to the complex shape of the Gypsy pulse. These data are from the first studies in a series of bioeffects studies of high-power microwave exposure. Other bioeffects investigations using these sources are under way.

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TABLE OF CONTENTS

List of Figures

List of Tables

BEHAVIORAL RESPONSE OF RATS EXPOSED TO HIGH-POWER MICROWAVE RADIATION

INTRODUCTION

Safety standards for exposure to radiofrequency radiation (RFR) for U.S. Air Force (USAF) personnel are based upon the potential biologic consequences of exposure to such environments. Most studies have shown no differences between pulsed and continuous-wave (CW) radiation with respect to bioeffects (1). In these studies the peak-to-average ratios ranged from 1000 to 10,000:1. Newly developed and developing technologies, designed for specific USAF applications, have peak powers in the kilowatt per square centimeter range with nanosecond pulse widths, with peak-to-average ratios much higher than heretofore available. No bioeffects data are available for these intense pulses, and since there may be implications for the setting of personnel safety standards, such data are urgently needed.

Behavioral studies were the first chosen for investigation of these unique pulsed radiations since behavioral changes appear to be among the most sensitive measures of biologic effects of RFR (2). There are numerous published reports of changes seen in animal behavior as a result of microwave exposure (3). Most such studies reported have used exposures of minutes to hours at relatively low-power densities (1-20 mW/cm^2), though there have been some investigations with short-exposure durations (e.g., 10 s) (4). Many researchers have concluded that behavior is disrupted by RFR at or above specific absorption rates (SAR) of about one-quarter of the resting metabolic rate of the animals (2). Since the average power density of these ultrashort, intense pulses would be hundreds of decibels down from the peak power, the absorbed energy from a single pulse would be very small in comparison to the resting metabolic rate. Hence, any changes in behavior noted as a result of these pulses would probably not be dependent upon changes in whole-body temperature.

METHODS AND MATERIALS

Radiofrequency Radiation Exposures

Exposures at the USAF School of Aerospace Medicine (USAFSAM) were made with a Cober, Inc. peak power simulator. This emitter consists of a local oscillator-controlled klystron amplifier. All experiments were made using the L-band transmitter operating at 2.066 GHz in the CW mode. The exposure time of 250 ms was set with a Hewlett Packard Model 8011A pulse generator; exposure time and frequency were measured with a Hewlett Packard 8566A spectrum analyzer.

Exposures at the Air Force Weapons Laboratory (AFWL) at Kirtland AFB, New Mexico, were made using the Gypsy virtual cathode oscillator (vircator) pulsed-microwave emitter (Fig. 1) (5). The oscillator is driven by a 500-kV water-filled Blumlein pulse power source, with a nominal pulse width of 140 ns, and operated at 1.64 GHz. The microwave energy produced by the oscillator is radiated by a 1.22-m (48 in.) diameter conical horn antenna in the TM01 mode.

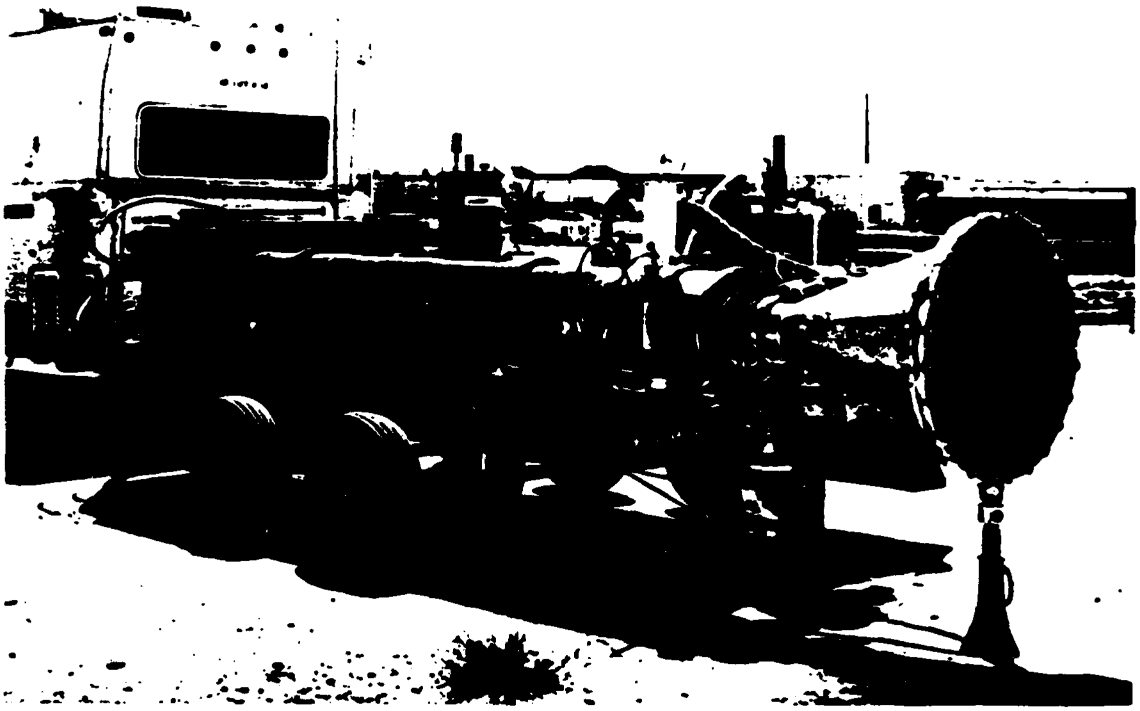

Figure 1. The Gypsy high-power microwave emitter.

Figure 2 shows the microwave energy emanating from the Gypsy antenna illuminating an array of fluorescent tubes and indicating a single on-axis null, with the power being radiated as a symmetric annulus. Incident power density measurements were made with D-dot asymptotic conical dipole type free-field electric field sensors, manufactured by EG&G, Inc. The report by Voss et al. (5) gives details on these power measurements. All exposures of animals were made either 1 m (3.28 ft), 2 m (6.56 ft), or 4 m (13.1 ft) in front of the horn antenna, and 9 deg to the right (as viewed from inside the horn) of the boresight.

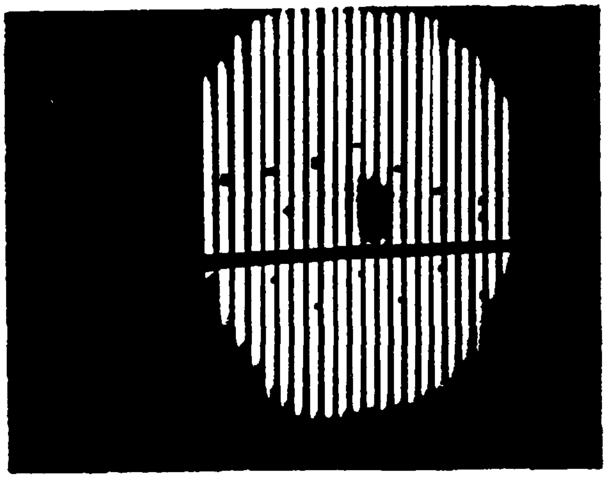

Figure 2. The shape of the microwave pulse from the Gypsy emitter as it illuminates an array of fluorescent tubes. The on-axis null is characteristic of the TM01 mode (5).

Figure 3 shows a map of the field at 4 m (13.1 ft), indicating the peaks at 9 deg from the boresight, with a null on axis. The behavioral manipulanda was placed on a wooden platform to raise it to the level of the middle of the horn antenna.

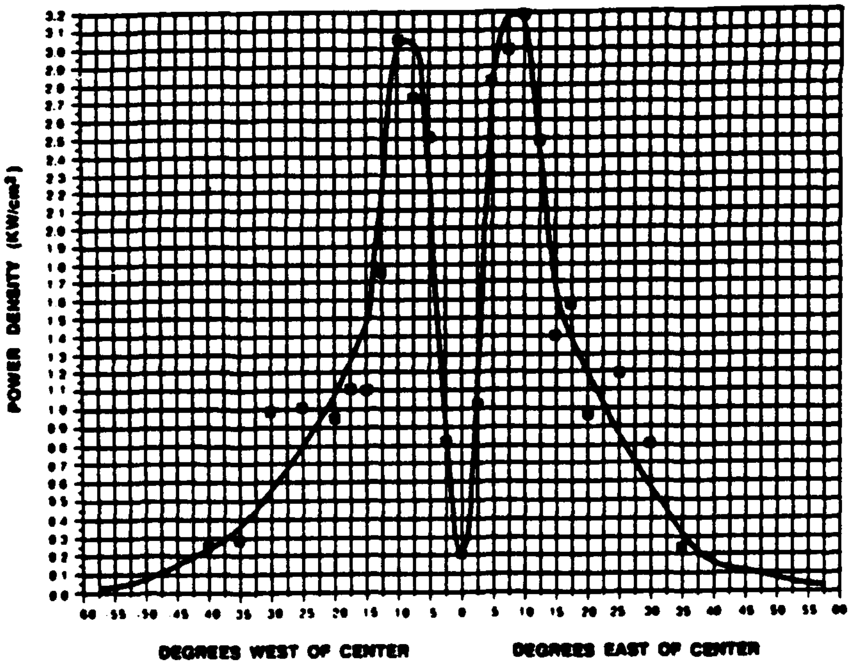

Figure 3. Field map of the Gypsy emitter microwave pulse radiated by the conical horn antenna at 4 m (13.1 ft). Output power was 236 MW; frequency was 1.64 GHz (5).

The power density could be reduced significantly by stuffing the horn antenna with horsehair impregnated with carbon particles and taping aluminum foil over the mouth of the horn.

Ionizing Radiation Dosimetry

Since the production of RFR entails acceleration of electron beams across voltages large enough to generate x-rays, some quantification of ionizing radiation was necessary. This dosimetry was done using Harshaw type lithium fluoride (LiF) thermoluminescent dosimeters (TLD). Dosimeter response was calibrated on a Cs-137 gamma source traceable to the National Bureau of Standards. These dosimeters have a relatively uniform energy response over the photon energy range of 50 to 660 keV which is believed to encompass the range of x-ray energies generated by the Gypsy vircator.

The x-ray dose from Gypsy was maximal along the boresight of the horn, where there is the null in the RFR. The x-ray dose was slightly less at the 9 deg off-center position where the RFR signal was maximal (see the Appendix for details). A 1.25-cm (0.47 in.) lead shield was placed in front of the behavioral apparatus to reduce the x-ray dose by 90% in some experiments.

Animals

We used male Fisher 344 rats, weighing 200-250 g, throughout these investigations. These animals were furnished from the breeding colony at the Inhalation Toxicology Research Institute, Albuquerque, New Mexico. This specific pathogen-free colony has been maintained for many years as a National Institutes of Health (NIH) Genetic Resource strain. An animal holding facility was established in a mobile trailer located adjacent to the exposure facility. A 0700 h/1900 h light/dark cycle was used; temperature was 24 ± 2 $^{\circ}C$. The rats were housed in standard clear plastic shoe-box type cages with wood shavings as litter. Standard laboratory chow and water were allowed ad libitum, except for those in the thirst satiation study, qv.

BEHAVIORAL TASKS AND RESULTS

All behavioral tasks were monitored by video, and recordings were made of each exposure session with a real-time date and time signal input.

Single Trial Avoidance

Description

The test apparatus consisted of two interconnected boxes constructed mostly of 0.95 cm (3/8 in.) thick Plexiglas; however, the side facing the horn antenna was made of 0.32 cm (1/8 in.) thick Plexiglas. The two boxes were connected through a door that could be opened remotely by compressed air-operated nylon pistons. The floor level was continuous for the two boxes. The animal was initially placed in the smaller box (5 cm [2 in.] x 7 cm [2.8 in.]

x 15 cm [5.9 in.]) of the two boxes. This smaller box had a slot cut for the animal's tail, and additional Plexiglas spacers could be placed as necessary to fully restrict lateral movement. The larger box measured 12 cm (4.7 in.) x 15 cm (5.9 in.) x 22 cm (8.7 in.), and was painted black. The floor in this larger box was made of 0.63-cm (1/4 in.) Plexiglas rods with 1 cm (0.4 in.) spacing between each rod.

Immediately before exposure, the rat was placed in the smaller box, with its head oriented toward the door. The interconnecting door between the two boxes was opened. When the animal's torso cleared the doorway, the single pulse exposure was made. As soon as possible after the exposure, the animal was removed from the large box and placed in the home cage. Ten minutes after exposure, the subject was returned to the smaller box and the interconnecting door was again opened. The datum of interest was the time it took the subject to enter the larger box, both for preexposure and postexposure. The time was recorded from the video tapes of each experiment. The photograph in Figure 4 (taken from the video screen) shows the animal in the apparatus.

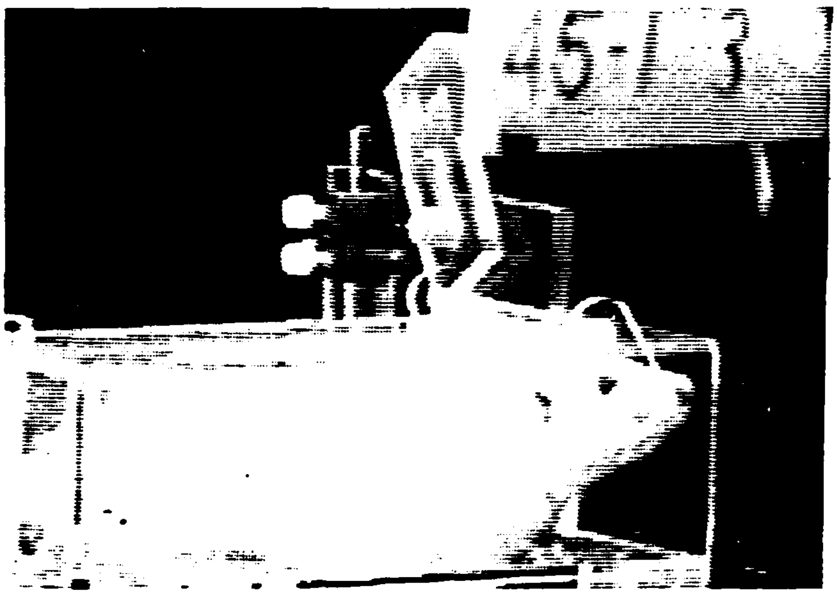

Figure 4. Single trial avoidance task apparatus. The animal is in the small box, and the interconnecting door to the large box is open.

Exposures using the Cober peak power simulator were made over a 5-day period, with 2 animals being exposed at each of 5 different power levels daily. Exposures at each power level were spread randomly over the workday, 0830-1630 hours.

Results

Table 1 lists some of the parameters for this behavioral task tested on the USAFSAM peak power simulator.

TABLE 1. DESIGN FOR SINGLE TRIAL AVOIDANCE TASK
USAFSAM PEAK POWER SIMULATOR

Power Output (kW)	11	9	7	5	0
Mean time held in small box preexposure (s)	19.9	18.8	21.8	21.4	18.2
Mean time held in small box before test (s)	17.7	15.5	15.4	16.0	16.9
Mean time between exposure and test (s)	611	622	604	619	616
Number of subjects	9	10	10	10	10

In analyzing the data from the single trial avoidance, the mean time for entry into the large box test (10-min postexposure) was compared to the preexposure entry time using the Kruskal-Wallis rank sums (6) at the .10 alpha level.

Table 2 lists the differences in time to entry into the large box on testing after exposure compared to the preexposure time to entry (i.e., postexposure entry time minus preexposure entry time). At $\alpha = .10$, entry into the large box was delayed by exposures at 11 kW and 9 kW compared to the 0 power group.

TABLE 2. DIFFERENCES IN ENTRY TIME USING THE USAFSAM PEAK POWER SIMULATOR

Output power (kW)	11	9	7	5	0
	6	6	4	1	0
	0	-2	0	1	7
	1	1	3	-1	-4
	>60	45	2	3	0
	8	2	2	1	1
	4	1	-2	5	2
	1	5	5	10	-1
	-4	1	3	5	1
	6	48	0	1	-1
		1	0	-1	-1
Mean	9.1	10.8	1.7	2.5	0.4
SD	19.4	19.0	2.2	3.4	2.8

Table 3 gives some parameters for the single trial avoidance task exposures with the Gypsy emitter. The RFR power densities at 1 m (3.28 ft) for these exposures were: full power ("T") = 7.5 ± 0.7 kW/cm^2; RF attenuated ("X") = 1.9 ± 0.7 W/cm^2; and RF and x-ray attenuated ("N") = 4.2 ± 0.9 W/cm^2.

TABLE 3. DESIGN FOR SINGLE TRIAL AVOIDANCE TASK
GYPSY EMITTER

	Full power "T"	RF attenuated "X"	RF & x-ray attenuated "N"
Mean time held in small box preexposure (s)	55.3	59.3	54.0
Mean time held in small box before test (s)	25.8	29.6	28.0
Mean time between exposure and test (s)	634	623	626
Number of subjects	8	10	9

Table 4 lists the differences in time to entry into the large box on testing after exposure compared to the preexposure time to entry (i.e., post-exposure entry time minus preexposure entry time). There are no significant differences among the treatment groups with the Gypsy emitter, using the Kruskal Wallis rank sums test.

TABLE 4. DIFFERENCES IN ENTRY TIME USING THE GYPSY EMITTER

	Full power	RF attenuated	RF & x-ray attenuated
	0	-1	0
	1	-1	-1
	2	2	-1
	0	0	0
	0	-1	2
	0	-3	0
	0	1	0
	0	0	0
		0	0
		2	
Mean	0.4	-0.1	0
SD	0.7	1.5	0.9

Thirst Satiation

Description

The test box measured 14 cm (5.5 in.) x 17 cm (7 in.) x 25 cm (9.8 in.) and was made of 0.95 cm (3/8 in.) thick Plexiglas, except for the side facing the antenna which was made of 0.32 cm (1/8 in.) thick Plexiglas. The floor consisted of 0.63 cm (1/4 in.) rods with 1 cm (0.4 in.) spacing. The drinking spout apparatus was located on the outside of the box, so that the animal had to reach through a small hole in the wall in order to lick. The spout was positioned 4.1 cm (1.6 in.) above the floor and 5 cm (2 in.) in from the exposure side of the box, and was located between two supports for the fiber-optic measuring device. There was a 0.95 cm (0.37 in.) clearance between the two ends of the fiber optic for the animal's nose and tongue. The support mechanism for the water spout and fiber-optic system was hinged at the top of the box, and could be swung away from the access hole by means of an air-driven nylon piston. This arrangement was necessary to prevent possible coupling of the animal with the water-filled spout during actual exposure.

The rats were made thirsty over a period of 5 days by allowing them access to water only during two daily drinking periods. Four rats at a time were placed in replicas of the test box for 30-min periods. Water flow through the spout was 15 to 20 drops per minute, the same rate used during testing. In this manner, the rats learned the location of the spout, and they competed vigorously during most of this 30-min period. The second daily watering session consisted of a 10-min period late in the day in which a standard water bottle was placed in each home cage. Figure 5 is a photograph (from the video screen) of the rat in the test apparatus.

Figure 5. Water satiation task apparatus. The animal obtains water by licking the spout. Each lick interrupts a light beam and produces a count on a recorder.

On test day, one rat at a time was placed in the test box. The rats were allowed 2 to 3 min to acclimate to the box; then the exposures were made after 45 s of imbibing. Each lick of the water spout interrupted the fiber-optic circuit and produced a mark on heat sensitive paper of a Gulton Model TR-711 single channel recorder. Recording was stopped during actual exposure. Start of exposure was also recorded on the paper tape. The data used for analysis were the total licking time in 10-s bins during 30-s epochs immediately pre- and postexposure; and in 30-s bins during a 3.5-min exposure epoch (this epoch also included the two 30-s epochs pre- and postexposure as bins) (Table 5).

TABLE 5. EXPERIMENTAL DESIGN FOR THIRST SATIATION TASK EXPOSURE

10-s bins	t-3 t-2 t-1		t+1 t+2 t+3				
30-s epochs	t-30		t+30				
30-s bins	t-30	t+30	t+60	t+90	t+120	t+150	t+180
	3.5-min epoch						

The time of the first postexposure drinking response was also noted to make comparisons against all treatment groups.

Each animal's condition was carefully noted during the test period. Weight loss of more than 15% was seen in only 2 animals. Maximum weight loss of any tested animal was 15.3% and the mean loss for 71 animals was 10.2%±2.7 (SD). The bulk of the weight loss was probably due to gut emptying.

Results

Tests at USAFSAM using the Cober peak power simulator were made using 5 different power outputs: 0 kW, 5 kW, 7 kW, 9 kW, 11 kW. The time to the first drinking response postexposure was compared by a one-factor analysis of variance (ANOVA)(7). The total times spent drinking by 10-s and 30-s bins were compared by a one-factor repeated measurements analysis of variance (MANOVA) (7). Simultaneous multiple comparison procedures were used to identify which treatments differed when there were radiation effects. Figure 6 shows the mean time to the first drinking response postexposure for the USAFSAM peak power simulator. Though there appears to be relationship between the output power and drinking response time, there are no statistically significant differences. Figures 7 and 8 show the licking responses for the 10-s and 30-s bins respectively for the USAFSAM peak power simulator.

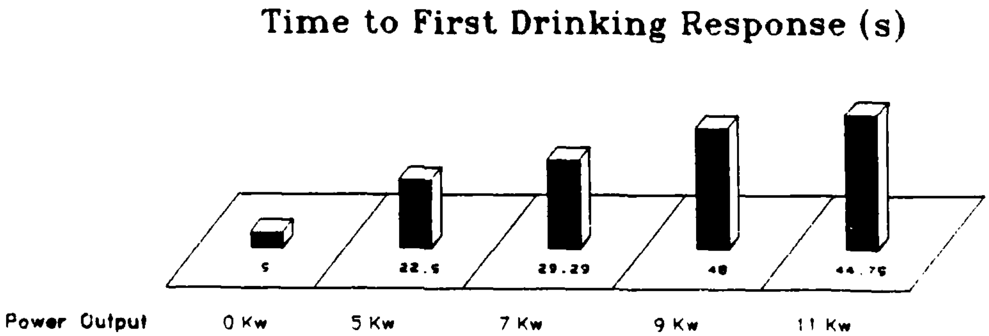

Figure 6. Time to first drinking response postexposure to the USAFSAM peak power simulator. There are no significant differences among the exposure groups.

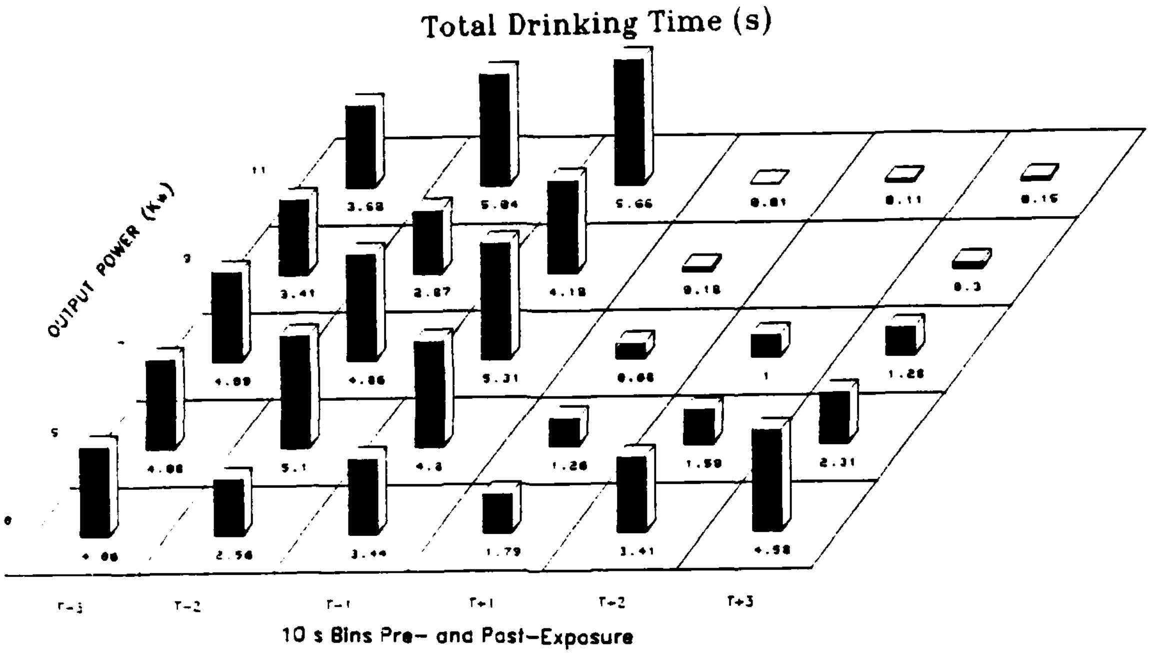

Figure 7. Total time spent drinking in 10-s bins preexposure (T-3, T-2, T-1) and 10-s bins postexposure (T+1, T+2, and T+3) to the USAFSAM peak power simulator at the output power indicated.

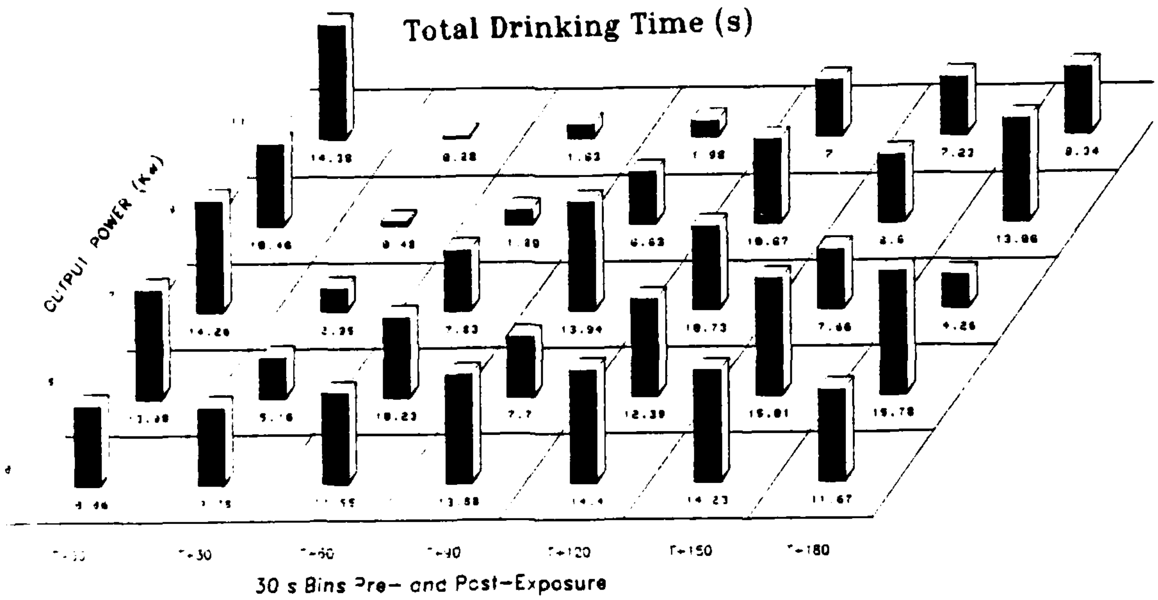

Figure 8. Total time spent drinking in 30-s bins preexposure (T-30), and 30-s bins postexposure (T+30 through T+180) to the USAFSAM peak power simulator at the output powers indicated.

Tables 6 and 7 list the significant findings from these data.

TABLE 6. ANALYSIS OF THIRST SATIATION DATA: 10-S BINS

At $\alpha = .05$, the MANOVA detected treatment effects at t+1, t+2, and t+3.

At $\alpha = .10$, simultaneous testing detected effects at t+30:
The 9-kW treatment group drank less than the 0-kW group.
The 11-kW treatment group drank less than the 0-kW group.
Simultaneous testing did not detect any other significant differences.

Candidates for triggering other significant differences (t+1 and t+3): 9-kW and/or 11-kW treatment group drank less than 0-kW group.

TABLE 7. ANALYSIS OF THIRST SATIATION DATA: 30-S BINS

At $\alpha = .05$, the MANOVA detected treatment effects at t+30, t+60, and t+90.

At $\alpha = .10$, simultaneous testing detected that at t+30:
The 9-kW treatment group drank less than the 0-kW group.
The 11-kW treatment group drank less than the 0-kW group.

Candidates for triggering other significant differences (t+30 and t+90): 9-kW and/or 11-kW treatment group drank less than 0-kW group.

The treatment groups used in the exposures to Gypsy were somewhat different and are shown in Table 8.

TABLE 8. EXPERIMENTAL DESIGN FOR THIRST SATIATION TASK
GYPSY EMITTER

TREATMENT

DISTANCE (M)	Full power "T"	RF attenuated "X"	RF & x-ray attenuated "N"	ANIMALS
4	7	8	8	23
2	10	8	-	18
1	12	10	8	30
ANIMALS	16	26	29	71

Data from the Gypsy experiments were analyzed using a two-factor ANOVA for time to first drinking response, and the total time spent drinking by 10-s and 30-s bins was analyzed by a two-factor MANOVA (7). Because of the data missing in one cell (2 m X "N"), the data were analyzed in three ways:

Case a: With a blank at this position

Case b: Discounting all 2 m data

Case c: Discounting all "N" data

The measured power densities for each of the treatment groups are shown in Table 9.

TABLE 9. GYPSY EXPOSURE POWER DENSITIES $\pm$ SD

Distance from antenna	Full power "T"	RF attenuated "X"	RF & x-ray attenuated "N"
4 m	2.2 ± 0.9 kW/cm^2	2.0 ± 1.3 W/cm^2	1.9 ± 0.3 W/cm^2
2 m	4.1 ± 0.3 kW/cm^2	27 ± 23 mW/cm^2	--
1 m	8.2 ± 0.6 kW/cm^2	4.2 ± 1.7 W/cm^2	3.8 ± 1.5 W/cm^2

Figures 9 and 10 show the licking responses after exposure to the Gypsy emitter for the 10-s and 30-s bins respectively. Tables 10 and 11 list the significant findings from these data.

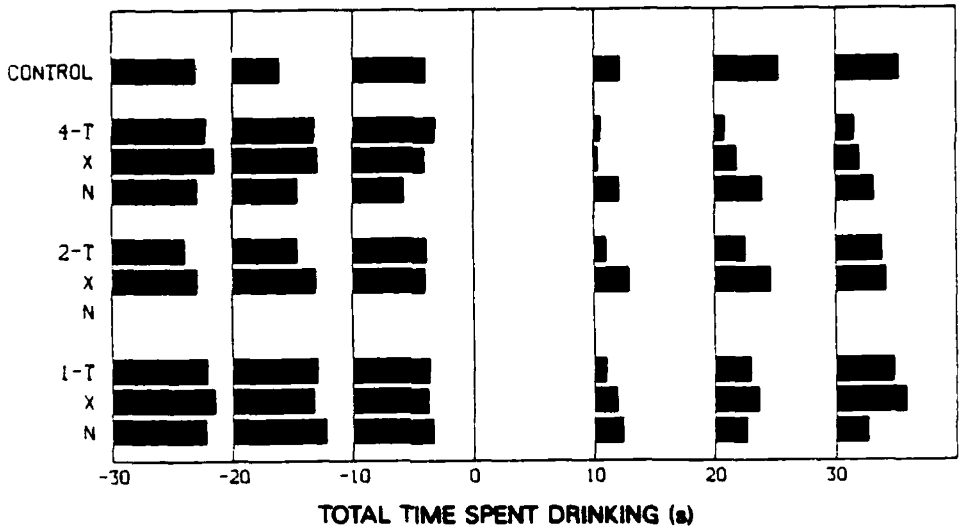

Figure 9. Total time spent drinking in 10-s bins preexposure and postexposure to the Gypsy emitter. Controls were run with no power output. "T" is the unattenuated pulse; "X" is the microwave energy attenuated; "N" is with both microwave energy and x-ray energy attenuated. 4, 2, and 1 are 4-m, 2-m, and 1-m distance from the horn antenna respectively.

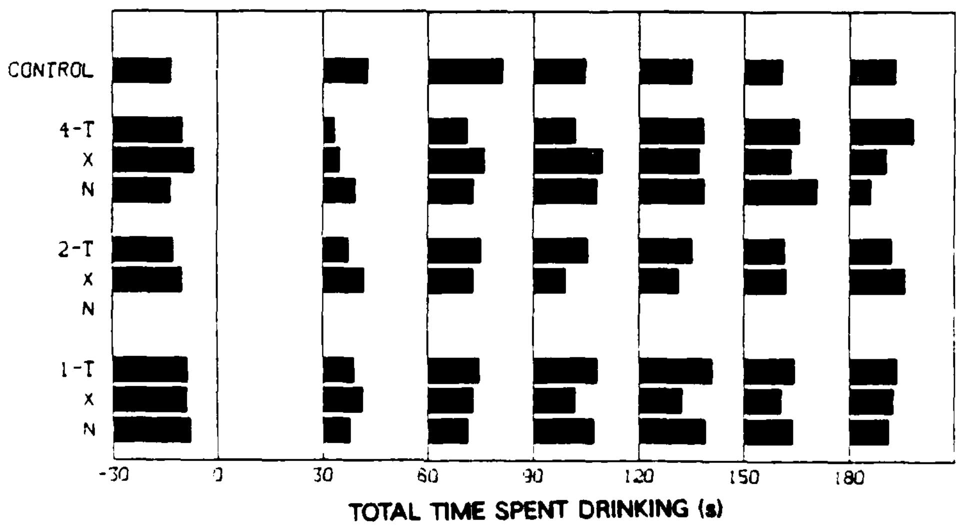

Figure 10. Total time spent drinking in 30-s bins preexposure and postexposure to the Gypsy emitter. Controls were run with no power output. "T" is the unattenuated pulse; "X" is the microwave energy attenuated; "N" is with both microwave energy and x-ray energy attenuated. 4, 2, and 1 are 4-m, 2-m, and 1-m distance from the horn antenna respectively.

TABLE 10. ANALYSIS OF THIRST SATIATION 10-S BIN DATA

Analysis by Case a:
At t+1, T < N, p<.05
At t+3, 4M < 1 M, p<.05
Analysis by Case b:
At t+1, T < N, p<.05
At t+1, X < N, p<.05
At t+3, 4M < 1M, p<.05
At t+1, 4M < 1M, p<.05
Analysis by Case c:
At t+1, T < X, p<.05
At t+3, 4M < 1M, p<.05
At t+1, 4M < 2M, p<.10
At t+2, T < X, p<.10

TABLE 11. ANALYSIS OF THIRST SATIATION 30-S BIN DATA

Analysis by Case a:
At t+30, 4M < 1M, p<.05
Analysis by Case b:
At t+30, 4M < 1M, p<.05
At t+180, N < T, p<.10
Analysis by Case c:
At t+30, 4M < 1M, p<.05
At t+120, T < X, p<.10

Analysis of the 10-s bin data shows that, for each case, the animals exposed at 4 m drank less during the third 10-s bin than those exposed at 1 m.

Balance Test

Description

In this task animals were trained to walk on a slowly rotating (15 rpm) rod (rotarod), over an ice water bath. The rats usually require 3 training sessions to be able to perform to a criterion response (i.e., continue walking on the rotarod without attempting to escape). The rotarod was made of

Plexiglas, 4 cm (1.6 in.) in diameter and 12 cm (4.7 in.) in width. The axle and pulley, also made of Plexiglas, were mounted on two Plexiglas supports, 14 cm (5.5 in.) x 29 cm (11.4 in.). The supports were in turn mounted on a 15 cm (5.9 in.) x 60 cm (23.6 in.) Plexiglas base. The pulley was driven by a tygon tubing belt attached to a small electric motor placed well out of the electromagnetic field. After sufficient training, the rats could easily perform at this speed for several minutes (8). Figure 11 is a photograph (taken from the video screen) of a rat on the apparatus.

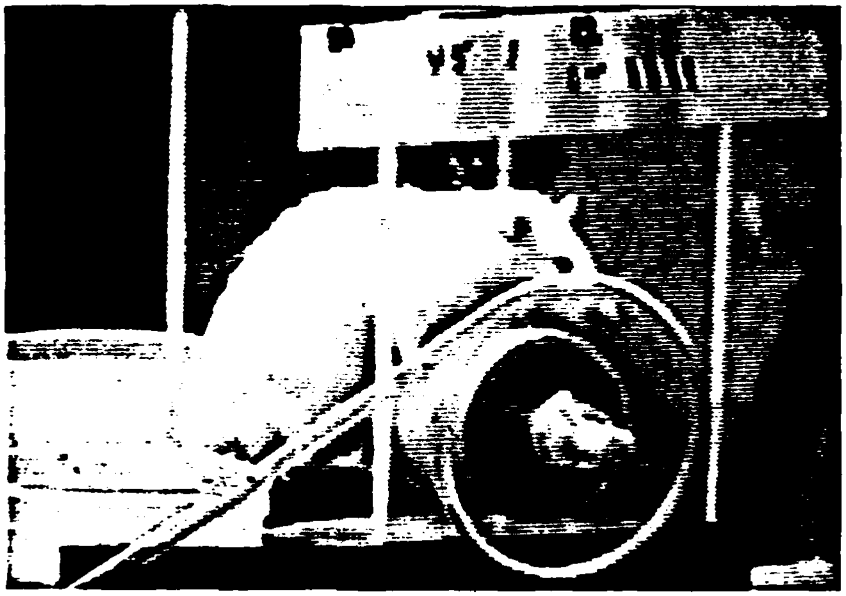

Figure 11. Animal performing on the rotarod. The trained rat can continue walking on this rotating rod for several minutes without falling.

Results

None of the animals lost their balance during any exposure. However, observation of the video tapes revealed an apparent difference in the "flinch" reaction (Table 12) by the animals exposed at full power versus those exposed at attenuated power. An attempt was made to subjectively quantitate these observations. The tape of each animal's exposure session was observed several times and a crude score of the reaction was assessed: 0 to 4+. There are no significant differences among the treatment groups using the Kruskal Wallis rank sums test; $H = 3.9$, $df = 2$, $p = .14$.

TABLE 12. "FLINCH" REACTION OF RATS ON THE ROTAROD GYPSY EMITTER EXPOSURES

	Full power	RF attenuated	RF & x-ray attenuated
Reaction	2.7±1.5*	1.2±1.0	1.2±0.8
Number of subjects	6	6	6

*Score ± SD

DISCUSSION

This is the first report of a bioeffects investigation using such ultrashort RFR pulses. This report asks more questions than it answers. The thirst satiation study revealed several significant differences in drinking response postexposure compared to the preexposure responses. The greater effect in drinking response that occurs at 4 m compared to 1 m is one of the more interesting differences. The far-field region of the Gypsy emitter frequency starts at approximately 4 m (5). Whether exposure in the far-field is related to the difference in observed bioeffect is problematical, given the complexities of the pulse shape and field distribution.

The results from the thirst satiation tests using the USAFSAM peak-power simulator clearly indicate that the rats exposed to the high-power microwaves imbibed less than unexposed animals. A consideration of the thermal effects of exposure to the two different emitter sources indicates significant differences. Exposure of a 200-g rat to the Gypsy emitter gives the following: The Radiofrequency Radiation Handbook (9) gives a whole-body average SAR at 1.64 GHz of 0.45 mW/g per mW/cm^2. At 1 m from the Gypsy emitter the power density is about 8 kW/cm^2, giving a peak whole body SAR for a rat of 3.6×10^6 mW/g. As a rule of thumb, an SAR of 60 mW/g over 60 s gives a 1 °C rise in temperature. For the Gypsy exposure then, an SAR of 3.6×10^6 over 140 ns gives a temperature rise of 0.0084 °C. Similar computation of the temperature increase from exposure to the USAFSAM peak power simulator gives an SAR of 0.32 mW/g per mW/cm^2 at its operating frequency of 2.07 GHz. At 11 kW output, the power density is approximately 30 W/cm^2 for SAR of 9.6×10^3 mW/g for a 200-g rat. This SAR applied over .25 s gives a temperature increase of 0.7 °C. Thus, the exposure to the Gypsy emissions is trivial in terms of whole-body thermal effects, while exposure to the peak-power simulator produces a thermally significant temperature increase.

Exposures to radiation from both emitter sources, however, induced the rats to imbibe less water postexposure when compared to the preexposure condition. Whether or not these RFR-induced responses are qualitatively the same is unknown. On the other hand, the responses seen with the single trial avoidance indicates a significant difference between the rats exposed to

9- and 11-kW output from the peak-power simulator, but no difference with the Gypsy emitter. In this case, it may be that the thermal insult of the peak-power simulator is aversive to the rats.

Though there is no significant group difference, the rotarod results suggest that the rats may be perceiving the pulse from the Gypsy emitter in some manner. One possibility would be the microwave "hearing effect" (10).

The possibility of ionizing radiation effects with the Gypsy exposures cannot be ruled out. Induction of retrograde amnesia by a dose rate of 10^6 rad/s has been reported (11). The ionizing radiation dose with the Gypsy emitter is just slightly lower than this (2×10^5 rad/s; see Appendix).

This report documents the first bioeffects study done using a high-power, ultrashort pulse-width emitter. A series of studies using various high-power emitter sources has been planned as part of the USAF High Power Microwave Program, and work is in progress at this time.

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REFERENCES

1. Heynick, L. N. Critique of the Literature on Bioeffects of Radiofrequency Radiation: A Comprehensive Review Pertinent to Air Force Operations. USAFSAM-TR-87-3, June 1987.

2. Biological Effects of Radiofrequency Radiation. Elder, J. and Cahill, D. F. (Eds.). EPA Publ. 600/8-83-026F (1984).

3. Behavioral Effects of Microwave Radiation Absorption. Monahan, J. and D'Andrea, J. Eds. HHS Publ. FDA 85-8238, U.S. Department of Health and Human Services, Rockville, MD, August 1985.

4. Bermant, R., Reeves, D., Levinson, D., and Justesen, D. Classical conditioning of Microwave-Induced Hyperthermia in Rats. Radio Sci. 14(6S):201-207 (1979).

5. Voss, D., Demuth, G., Babbitt, A., Torraca, L., and Miera, B. Characterization of the RF Radiation from an Axially Extracted Cathode Oscillator Operated at 1.3 GHz. AFWL-TR (In Press) Air Force Weapons Laboratory, Kirtland AFB, NM (1987).

6. Nonparametric Statistical Methods. Hollander, M. and Wolfe, A., Eds., Chap. 6. New York: John Wiley and Sons, 1973.

7. Multivariate Statistical Methods. Morrison, D., Ed., Chap. 5. New York: McGraw-Hill, Inc., 1967.

8. Bogo, V., Hill, T., and Young, R. Comparison of Accelerod and Rotorod Sensitivity in Detecting Ethanol and Acrylamide-Induced Performance Decrement in Rats: Review of Experimental Considerations of Rotating Rod Systems. Neurotoxicol 2:765-787, 1981.

9. Durney, C.H., Johnson, C.C., Barber, P.W., Massoudi, H., Iskander, M.F., Lords, J.L., Ryser, D.K., Allen, S.J., and Mitchell, J.C. Radiofrequency Radiation Handbook. (Second Edition). SAM-TR-78-22, May 1978.

10. Chou, C., Guy, A., and Galambos, R. Auditory Perception of Radiofrequency Electromagnetic Fields. J Acoust Soc Am 71:1321-1334 (1982).

11. Wheeler, T., Hardy, K., and Blick, D. Retrograde Amnesia in Rats Produced by Electron Beam Exposure. USAFSAM-TR-83-3, February 1983.

APPENDIX

IONIZING RADIATION MEASUREMENTS

The production of high-power microwave pulses by the Gypsy emitter entails the acceleration of an electron current pulse across a high-voltage field of sufficient energy to generate penetrating x rays. Measurements were made to determine the magnitude of the x-ray component in the exposure configurations used for the biobehavioral experiments. Preliminary dosimetric measurements at the Gypsy facility showed that the x-ray dose at 1 m (39.37 in.) from the horn antenna was approximately 28-34 mR/pulse. With a 140-ns pulse width, this corresponds to an in-air exposure dose rate of 2×10^5 R/s.

Victoreen condenser R-meter chambers (Model 576) and Harshaw type 100 Lithium fluoride (LiF) powder thermoluminescent dosimeters (TLD) were used for these x-ray measurements. The in-air x-ray field measurements were done with condenser R-meter chambers and TLDs. A 5-cm (2 in.) diameter cylindrical water-filled phantom, approximating the size of the rats used in the experiments, was used to establish the entrance, midline, and exit doses to the animals. Type 100 TLDs were used in the phantom measurements. The dosimeter responses were calibrated on a UDM-1A Cs-137 gamma source, whose output calibration is directly traceable to the National Bureau of Standards (NBS). The R-chambers used are known to have a relatively uniform photon energy response over the range of x-ray energies generated by the Gypsy emitter. The R-chamber responses were corrected for temperature and pressure; the elevation at Kirtland AFB, New Mexico (1585 m [5200 ft]) required a pressure correction factor of X 1.23. These ion chambers are also known to show some loss of sensitivity due to high-dose rate saturation. Comparison of the measured chamber response, corrected for temperature, pressure, and Cs-137 calibration factor with the preliminary TLD dose measurements indicates that this correction should be 1.3 X.

X-ray dosimetric measurements were made on-axis (boresight) where the microwave field is at a minimum, and at approximately 9 deg off-axis where the microwave field was maximum. Two exposure configurations were examined: (1) with the microwave field unattenuated (full power), and (2) with foam attenuation material stuffed in the horn. Power density measurements in the latter configuration indicate a reduction of 3 orders of magnitude (from 3 kW/cm^2 to 1 W/cm^2). The x-ray dose/pulse was reduced by this attenuation about 37% of the unattenuated pulse. Subsequently, during the animal experiments a third exposure configuration was used in which a 0.63 cm (1/4 in.) lead sheet was placed between the animal and the horn antenna to block the x-ray component. No calibration measurements were made with this configuration, but TLDs were exposed with some of the animals; results are shown in Table A-1.

The results of the in-air x-ray dose measurements are shown in Figures A-1 and A-2. The x-ray dose/pulse on the horn antenna boresight was 1.27 X the dose/pulse at the off-axis position for both configurations. For the attenuated experiments it was recommended that the animals be located on the boresight. This configuration would compensate in large part for the reduction of the x-ray dose while further reducing the power density.

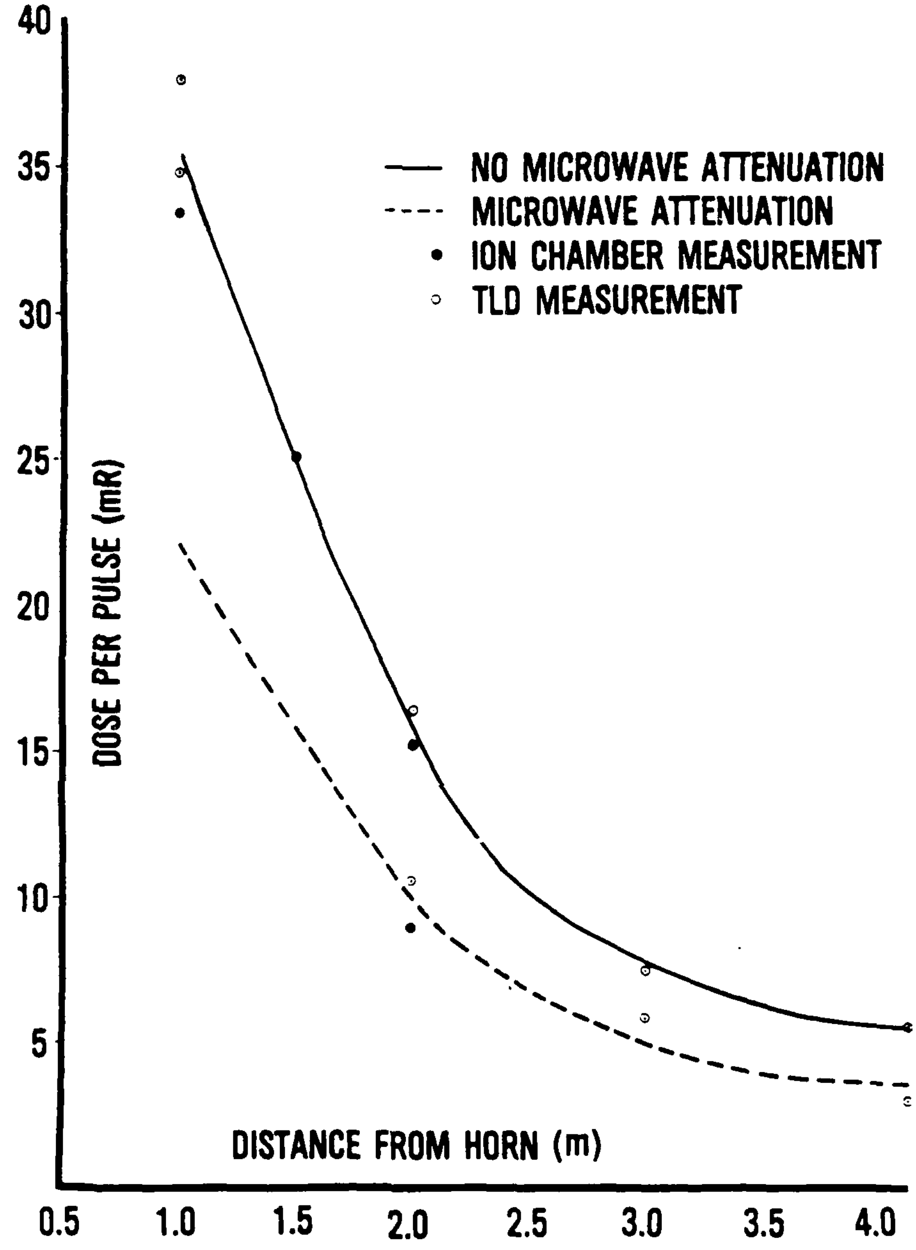

Figure A-1. In-air x-ray dose measurements. These measurements were made on the boresight of the horn antenna at the point where there was a null in the microwave power density. Microwaves were attenuated by stuffing the horn with carbon particle impregnated horse hair material.

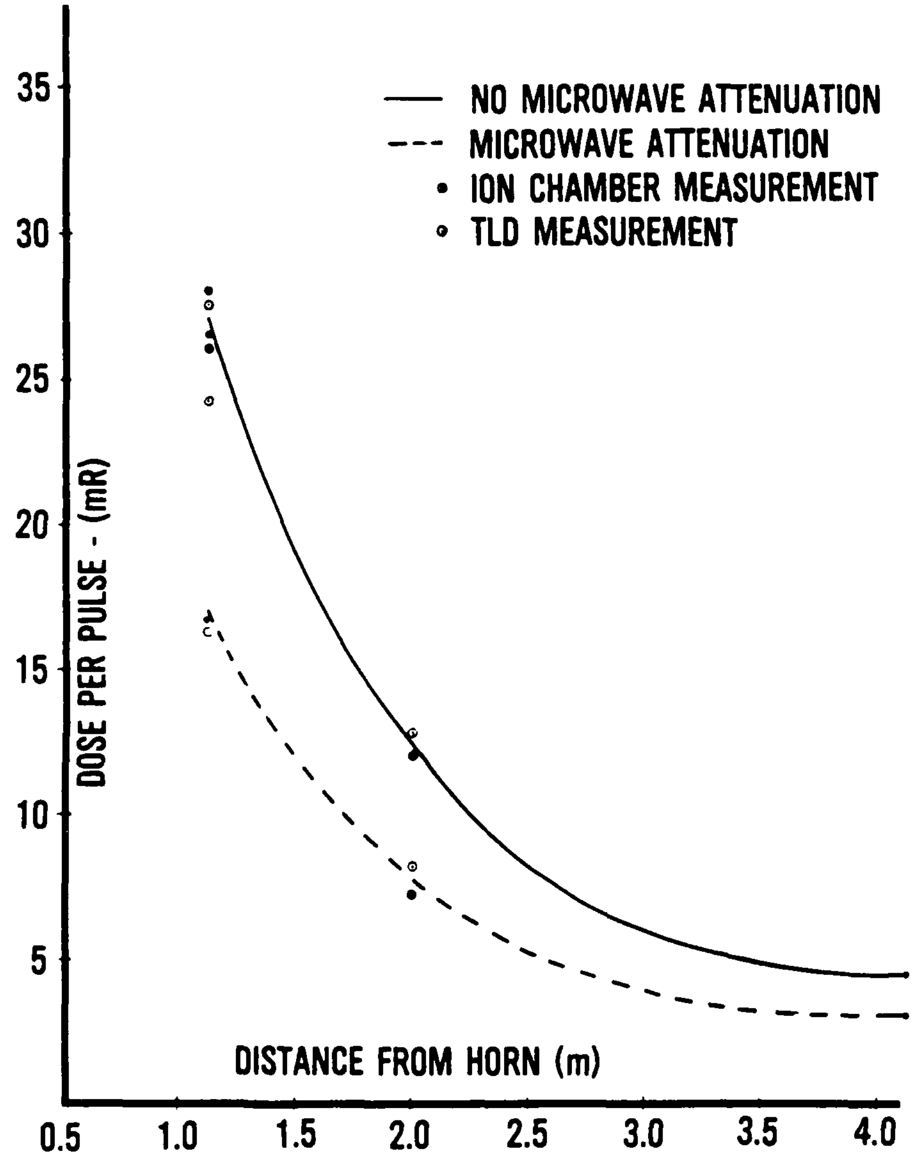

Figure A-2. In-air x-ray dose measurements. These measurements were made 9 deg off-axis from the boresight. Microwaves were attenuated by stuffing the horn with carbon particle impregnated horse hair material.

Table A-1 summarizes the results of the phantom x-ray dosimetry measurements for both the attenuated and unattenuated modes. These measurements indicate that the phantom midline x-ray doses are about the same as the in-air doses at the phantom position. The entrance dose was approximately 1.3 X the midline dose, and the exit dose was about 0.5 X the midline dose.

TABLE A-1. PHANTOM DOSIMETRY

Mode	In air	Phantom center	Phantom anterior	Phantom posterior
Unattenuated (2 m)	12.8*	13.5	17.0	6.2
Attenuated (2 m)	8.2	8.1	10.9	---

*mR/pulse

The results of the TLD monitors exposed with the animals are shown in Table A-2. Dosimeters 19-25 were exposed to 8 to 12 pulses at 1-m distance in each of the configurations as described in the table. The dosimeters exposed on the top of the behavior box (#'s 19, 20, 22, and 24) indicate that moving the animal from the off-axis position to the horn boresight in the attenuated mode did compensate reasonably well for the x-ray dose reduction. The TLD exposed with the lead shield (#25) indicated that the lead shield reduced the x-ray dose to less than 10% of the unshielded value. Dosimeters #39-54 were exposed during the balance task. Dosimeters #39, 41, and 47 agree reasonably well with the predicted dose for that location and configuration. The low-dose response for #40 may be due to a faulty pulse. The over response of #46 is unexplained; the dose seems to indicate multiple exposures. Repeat Cs-137 calibration checks with TLDs tend to corroborate the measure dose values. Also unexplained are the responses of #52-54 (with lead shielding). Based on the dose/pulse of the unshielded dosimeters #39, 41, and 47, the lead shielded dose values should have been about 3-4 mR/pulse.

TABLE A-2. TLD X-RAY DOSE MONITORING

TLD number	Total dose	Number of pulses	Dose per pulse	Exposure configuration
19	288 mR	12	24.0 mR	Unattenuated; off-axis; top of box
20	227 mR	10	22.7 mR	Attenuated; on-axis; top of box
21	269 mR	10	26.9 mR	Attenuated; on-axis; front of box
22	221 mR	10	22.1 mR	Attenuated; on-axis; top of box
23	258 mR	10	25.8 mR	Attenuated; on-axis; front of box
24	173 mR	8	21.6 mR	Unattenuated; off-axis; top of box
25	16 mR	9	1.8 mR	Attenuated; lead; top of box
39	45 mR	1	45.0 mR	Unattenuated; off-axis; front
40	8 mR (?)	1	8.0 mR	Unattenuated; off-axis; front
41	37 mR	1	37.0 mR	Unattenuated; off-axis; front
46	229 mR (?)	1	229.0 mR	Attenuated; off-axis; front
47	41 mR	1	47.0 mR	Attenuated; off-axis; front
52	26 mR	1	26.0 mR	Attenuated; lead; off-axis; front
53	37 mR	1	37.0 mR	Attenuated; lead; off-axis; front
54	26 mR	1	26.0 mR	Attenuated; lead; off-axis; front

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